PULSATING TYPE IV SOLAR RADIO BURSTS

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Abstract. Several models for pulsating type IV radio bursts are presented based on the assumption that the pulsations are the result of fluctuations in the synchrotron emission due to small variations in the magnetic field of the source. It is shown that a source that is optically thick at low frequencies due to synchrotron self-absorption exhibits pulsations that occur in two bands situated on either side of the spectral peak. The pulsations in the two bands are $180^\circ$ out of phase and the band of pulsations at the higher frequencies is the more intense. In contrast, a synchrotron source that is optically thin at all frequencies and whose low frequency emission is suppressed due to the Razin effect develops only a single band of pulsations around the frequency of maximum emission. However, the flux density associated with the later model would be too small to explain the more intense pulsations that have been observed unless the source area is considerably larger than presently seems reasonable.

1. Introduction

One interpretation of the quasi-periodic fluctuations (pulsations) that are occasionally seen in type IV radio bursts is that they are caused by changes in the synchrotron emission of a source which result from fluctuations in the background magnetic field. This variable magnetic field is attributed to a standing magnetohydrodynamic wave that is set up in a magnetic flux tube (Rosenberg, 1970). In this paper the correctness of this model is assumed and it is shown how the presence of a low frequency cutoff of the type IV spectrum qualitatively affects the pulsations. The following four cutoff mechanisms and their effect on the pulsations will be explored: (1) synchrotron self-absorption, (2) Razin effect, (3) gyro-synchrotron absorption by thermal electrons, and (4) collisional (free-free) absorption.

2. Theory

The equations for the synchrotron emissivity and absorption coefficient are greatly simplified when the radiating electrons have attained ultra-relativistic energies. All of the results obtained in this section are for an isotropic power law differential energy spectrum in the ultra-relativistic limit. The modal dependence of the various quantities will be ignored. It will be shown in later sections that the results so obtained are in qualitative agreement with more realistic numerical computations.

Consider an electron energy spectrum

$$N(\gamma) d\gamma \sim \gamma^{-\Gamma} d\gamma, \quad \Gamma > 0, \quad (1)$$

where $\gamma$ is the electron Lorentz factor. Assuming a very tenuous plasma, the syn-
The synchrotron absorption coefficient associated with this energy spectrum is (Ginzburg and Syrovatskii, 1964)

\[ \kappa_v \sim B^{n-1} \nu^{-n} , \quad n = (\Gamma + 4)/2 , \tag{2} \]

and the volume emissivity is

\[ j_v \sim B^{m+1} \nu^{-m} , \quad m = (\Gamma - 1)/2 , \tag{3} \]

where \( B \) is the magnetic field of the source. The power law dependence exhibited in Equations (2) and (3) retains its usefulness even for a mildly relativistic population of electrons. In that case, however, \( m \) and \( n \) become slowly varying functions of frequency which must be determined by numerical computation.

The intensity emergent from a volume of depth \( L \) and with uniform magnetic field is given by

\[ I_v = \frac{j_v}{\kappa_v} (1 - e^{-\kappa_v L}) . \tag{4} \]

In the limit of large optical depth \((\kappa_v L \gg 1)\), Equation (4) reduces to

\[ I_v = \frac{j_v}{\kappa_v} \sim B^{-(n-m-2)} \nu^{n-m} \sim B^{-0.5} \nu^{2.5} , \tag{5} \]

and for the optically thin case \((\kappa_v L \ll 1)\), we have

\[ I_v = j_v L \sim B^{m+1} \nu^{-m} . \tag{6} \]

Assuming \( \Gamma > 1 \), we see from Equation (6) that in the optically thin portion of the spectrum the intensity is a monotonically increasing function of the magnetic field. On the other hand, in the optically thick regime Equation (5) shows that an increase in magnetic field causes a decrease in the emergent intensity. Thus, a periodic variation of the magnetic field will cause periodic variations in the synchrotron intensity, with these variations undergoing a \( 180^\circ \) phase shift across the peak in the spectrum.

The band of pulsations in the optically thick regime are insensitive to the steepness of the electron energy spectrum. However, for the optically thin band of pulsations, steeper energy spectra give rise to more intense pulsations. Similarly, the steep spectrum associated with an anisotropic momentum distribution will favor the generation of intense pulsations.

Now consider the case where the density of the cold background plasma is sufficient to cause the index of refraction to be slightly less than unity. As Ramaty (1969) has shown, this causes both the synchrotron emissivity and absorption coefficient to be significantly depressed (Razin effect) at frequencies less than \( \nu_r \), where

\[ \nu_r = 0.7 \nu_p^2/\nu_b . \tag{7} \]

The synchrotron emissivity and absorption coefficient remain unaffected by the ambient medium when \( \nu \gg \nu_r \). Here \( \nu_b \) is the nonrelativistic gyro frequency and \( \nu_p \) is the electron plasma frequency. We shall assume that the source is optically thin at all